THE GEO-SEQ PROJECT

Sally M. Benson and Larry Myer

Earth Sciences Division
E. O. Lawrence Berkeley National Laboratory
Berkeley, California 94720
smbenson@lbl.gov

ABSTRACT

The GEO-SEQ Project, established in May 2000, is a public-private R&D partnership sponsored by the U.S. Department of Energy (DOE) that will conduct a set of targeted, inter-related, applied R&D tasks to advance geologic sequestration technology. The project will take place over a three-year period and involves scientists and engineers from three DOE national laboratories working in collaboration with Stanford University, Texas Bureau of Economic Geology, Alberta Research Council, TNO Institute of Applied Geosciences, the U.S. Geological Survey and our five industry partners. The overall goals of the project are to:

- lower the cost of geologic sequestration;
- lower the risk of geologic sequestration; and
- decrease the time to implementation.

To accomplish these objectives, the project team will carry out four inter-related R&D tasks in cooperation with the DOE National Energy Technology Laboratory (NETL) and our industry partners, which include BP-Amoco, Chevron, Texaco, Pan Canadian Resources and Statoil. R&D tasks include: (1) development of co-optimization techniques for value-added sequestration technologies, (2) identification and evaluation of monitoring technologies and approaches, (3) improvement of reservoir models for predicting the performance of sequestration, and (4) improvement of the methodology and information available for capacity assessment. GEO-SEQ will also carry out public outreach; which includes five components: (1) sponsorship and participation in workshops, (2) active engagement of our advisory council, (3) a middle-school education program, (4) undergraduate and graduate research opportunities, and (5) a GEO-SEQ Web page that keeps our partners and the public informed about geologic sequestration, and the progress of the project. Interaction with the international community of researchers pursuing R&D in geologic sequestration is also critical to the success of this project.

PURPOSE AND INTRODUCTION

The purpose of the GEO-SEQ project is to establish a public-private R&D partnership that will:

- **Lower the cost of geologic sequestration** by: (1) developing innovative optimization methods for sequestration technologies with collateral economic benefits such as enhanced oil recovery (EOR), enhanced gas recovery (EGR), and enhanced coalbed methane production, and (2) understanding and optimizing trade-offs between CO_2 separation and capture costs, compression and transportation costs, and geologic sequestration alternatives.
- **Lower the risk of geologic sequestration** by: (1) providing the information needed to select sites for safe and effective sequestration, (2) increasing confidence in the effectiveness and safety of sequestration by identifying and demonstrating cost-effective monitoring technologies, and (3) improving performance-assessment methods to predict and verify that long-term

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sequestration practices are safe and effective and do not introduce any unintended environmental impacts.
- **Decrease the time to implementation** by: (1) pursuing early opportunities for pilot tests with our private sector partners, and (2) gaining public acceptance.

All of these activities will take place with the participation, advice, and cooperation of the U.S. Department of Energy's National Energy Technology Laboratory, Morgantown, WV, and our industry partners, thereby assuring the practicality of our approaches and resulting in rapid technology transfer. To ensure broad stakeholder input and wide dissemination of the results of this project, we will also establish an Advisory Council with membership that reaches beyond the immediate partners. In addition, we will prepare and disseminate educational and informational materials at timely intervals to inform the public about geologic sequestration. Interaction and engagement of the international community of researchers and government entities that are pursuing R&D in geologic sequestration are also critical to the success of this project.

PROJECT TEAM

The GEO-SEQ Project includes a core team of scientists and engineers from a number of organizations, including:

- Three of the U.S. DOE's national laboratories — Lawrence Berkeley National Laboratory (LBNL), Lawrence Livermore National Laboratory (LLNL) and Oak Ridge National Laboratory (ORNL)
- Stanford University
- Texas Bureau of Economic Geology (TBEG)
- U.S. Geological Survey (USGS)
- Alberta Research Council (ARC)
- TNO Institute of Applied Geosciences (TNO)
- Five industry partners — Chevron, Texaco, Pan Canadian Resources, BP-Amoco and Statoil.

In addition, through ongoing collaborations and our advisory committee, our team extends to include other universities and a number of public and private research organizations.

RESEARCH AND DEVELOPMENT PLAN

The GEO-SEQ project team is carrying out the four coordinated and inter-related applied R&D tasks listed in Table 1. The specific R&D tasks were selected on the basis of the results of an extensive sequestration roadmapping exercise sponsored by the Department of Energy (Reichle et al., 2000) and summarized in Benson (2000). Projects were also selected that take advantage of and leverage fundamental research that is supported by DOE's Geosciences Program in the Office of Science. In addition to the R&D tasks listed in Table 1, GEO-SEQ will also carry out public outreach, which includes five components: (1) sponsorship and participation in workshops, (2) active engagement of our advisory council, (3) a middle-school education program, (4) undergraduate and graduate research opportunities, and (5) a GEO-SEQ Web page that keeps our partners and the public informed about geologic sequestration, and the progress of the project.

PILOT TEST SITES

Our industry partners have confirmed the availability of three pilot test sites for evaluating technologies for monitoring sequestration of CO_2 in geologic formations. These include the Lost Hills Oil Field (Chevron) in the Central Valley, California, the Vacuum Oil Field (Texaco) near Hobbs, New Mexico, and the Weyburn Field (Pan Canadian Resources) near Regina, Saskatchewan. These pilot test sites will be used to evaluate how effectively high-resolution geophysical techniques, such as single- and cross-well seismic imaging, cross-well electromagnetic imaging, and possibly, electrical resistance tomography, can track the migration of CO_2 in geologic formations. We shall also use the pilot tests as an opportunity to develop tracer techniques for evaluating *in situ* CO_2 solubilization and mineralization rates.

If additional sites become available, these too will be evaluated as possible candidates for pilot testing of monitoring techniques or for evaluating newly developed co-optimation technologies from Task A.

Table 1: ***Applied R&D tasks for the GEO-SEQ Project.***

Task	Sub-Task	Investigators
Task A. Develop *sequestration co-optimization methods* for EOR, depleted gas reservoirs, and brine formations.	A-1. Co-optimization of carbon sequestration and EOR and EGR from oil reservoirs.	Franklin Orr and Anthony Kovscek, Stanford University
	A-2. Feasibility assessment of carbon sequestration with enhanced gas recovery in depleted gas reservoirs.	Curt Oldenburg and Sally Benson, LBNL Tony Kovscek, Stanford University
	A-3. Evaluation of the impact of CO_2, aqueous fluid, and reservoir rock interactions on the geologic sequestration of CO_2, with special emphasis on the cost implications.	Kevin Knauss and Carl Steefel, LLNL Karsten Pruess and Chin Fu Tsang, LBNL
	A-4. Life-cycle cost analysis for sequestration in brine formations.	Katherine Yuracko, ORNL
Task B. Evaluate and demonstrate *monitoring technologies* for verification, optimization, and safety.	B-1. Sensitivity modeling and optimization of geophysical monitoring technologies.	Larry Myer, Mike Hoversten, Don Vasco, Ernie Majer, LBNL Robin Newmark, LLNL
	B-2. Field data acquisition for CO_2 monitoring using geophysical methods.	Ernie Majer and Mike Hoversten, LBNL Robin Newmark, LLNL
	B-3. Application of natural and introduced tracers for optimizing value-added sequestration technologies.	David Cole and Jerry Moline, ORNL
Task C. Enhance and compare *computer simulation models* for predicting, assessing, and optimizing geologic sequestration in brine, oil and gas, and coalbed methane formations.	C-1. Enhancement of numerical simulators for greenhouse gas sequestration in deep, unminable coal seams.	Bill Gunter and David Law, ARC Karsten Pruess, LBNL Bert van der Meer, TNO Franklin Orr and Anthony Kovscek, Stanford University
	C-2. Intercomparison of models for simulating sequestration in geologic formations.	Karsten Pruess and Chin Fu Tsang, LBNL Kevin Knauss and Carl Steefel, LLNL
Task D. Improve the methodology and information available for *capacit*y assessment of sequestration sites.	Evaluate the capacity factor for a range of hypothetical and actual brine, oil and gas formations. Facilitate development of an integrated data base combining information on oil, gas, coal and brine formations suitable for sequestration using the U.S. Geological Survey GEO-Data Explorer Project (GEODE, see http://dss1.er.usgs.gov).	Susan Hovorka, P. Knox and T. Trembley, TBEG Sally Benson and Karsten Pruess, LBNL Roger Aines, LLNL Collaborators: Robert Burruss, USGS

PROGRESS

Early progress has been made in a number of areas and is highlighted below.

Carbon Sequestration Enhanced Gas Recovery (CSEGR)

Injection of CO_2 into depleted gas reservoirs has the potential to sequester significant quantities of CO_2 (140 GtC worldwide; IEA, 1997) while simultaneously enhancing CH_4 recovery. Many aspects of this approach for sequestration are favorable, including: (1) the carbon density for CO_2 is nearly twice that of CH_4 at typical reservoir pressures and temperatures; (2) the mobility ratio for CO_2 displacement of CH_4 is favorable, thereby limiting viscous fingering; (3) the greater density of CO_2 compared to CH_4 will lead to gravity segregation, thereby limiting mixing; and (4) revenues from the enhanced gas recovery can be used to offset the cost of sequestration. Nevertheless, valid concerns about degrading the quality of the produced gas with CO_2 have limited the development of this concept. A few studies have investigated the feasibility of CSEGR with mixed conclusions regarding the efficacy of this approach and more importantly have shown that the conclusions are highly dependent on the specific assumptions about the nature of the reservoir (Walker and Huff, 1964; Lewin and Associates, 1980; van der Burgt et al., 1992; Blok et al., 1997; and Wildenborg, 2000).

We have begun an investigation to develop a better understanding of the physical processes, reservoir characteristics and well-field parameters that are favorable for CSEGR. We have developed a version of the reservoir simulator TOUGH2 (Pruess et al., 1999) to study systems with H_2O, brine, CO_2 and CH_4 (Oldenburg et al., 2000). This simulator has been used to carry out a feasibility assessment of CSEGR in the Rio Vista Gas Field, the largest on-shore gas field in California. These studies, summarized in Oldenburg et al. (2000), show that the Rio Vista Gas Field is a potential candidate for CSEGR and that up to five years of enhanced production is possible before CO_2 concentrations exceed several percent at the production wells. Ultimately, up to 330 Mt of CO_2 could be sequestered here, equivalent to 80 years of CO_2 generated at a 680 MW power plant located nearby. The study also clearly demonstrates that gravity segregation limits mixing of CO_2 and CH_4 over decades.

Sensitivity Studies for Evaluating Geophysical Monitoring Techniques

A set of software tools that combines the output of reservoir simulators with forward and inverse geophysical models has been developed for evaluating which geophysical monitoring approaches have the spatial resolution and sensitivity needed to monitor CO_2 sequestration. This system has been used to design the surveys described below and to evaluate the effectiveness of seismic, electromagnetic and gravitational techniques for detecting CO_2 migration up a fault zone connecting two reservoirs. A description of this system and a discussion of the role of high-resolution geophysical techniques for monitoring sequestration has been summarized in Myer (2000).

Field Trials of High Resolution Geophysical Monitoring Methods

Baseline geophysical surveys (pre-CO_2 injection) for evaluating cross-well seismic, single-well seismic, and cross-well electromagnetic methods at the Lost Hills Oil Field will be completed in July 2000. Detailed planning for these tests is now complete and final preparations are underway.

Baseline surveys evaluating cross-well seismic methods for monitoring CO_2 migration at the Weyburn Oil Field (Hattenbach et al., 1999) will be carried out in August 2000. Detailed planning for these surveys is underway.

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